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less, probably, above unit area on *Mars* than in our atmosphere about the same area of Mount Whitney.

It is difficult to understand how so small an amount of water can keep a geometrical canal system on *Mars* in active operation.

March, 1910.

ON THE SPECTRUM OF *MARS* AS PHOTOGRAPHED WITH HIGH DISPERSION.

By W. W. Campbell and Sebastian Albrecht.

Let us recall that the solar spectrum, as viewed by terrestrial observers, is composite. Photospheric light, in passing out through the gases and vapors of the Sun's atmosphere, is selectively absorbed, with the result that many thousands of lines are introduced into the spectrum. These rays pass down through the Earth's atmosphere to the observer, and the absorption by water vapor and oxygen in the terrestrial atmosphere introduces many hundreds of additional lines, at definite points in the yellow, orange, and red regions. The observed spectrum of the Sun is in reality the spectrum of the Sun plus the spectrum of the Earth. The spectrum of the Moon, so far as our present problem is concerned, is simply this Sun-Earth spectrum.

The light from *Mars* is photospheric light, which passes out through the Sun's atmosphere, thence down through the atmosphere of *Mars* to the planet's crust, where a certain proportion is reflected out through the Martian atmosphere, and thence down through the Earth's atmosphere to the observer. The so-called spectrum of *Mars* is in reality the Sun's spectrum plus *Mars's* spectrum plus the Earth's spectrum.[1] Any water vapor and oxygen in the Martian atmosphere should introduce the same absorption lines which are introduced by the Earth's atmosphere in the Sun-Earth spectrum.

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[1] A little of the light would be reflected from the atmospheric strata of various heights without passing down to the planet's surface. It should also be noted that the rays do not pass normally through the planet's atmosphere, but have angles of incidence and reflexion with the strata equal on the average, in the present investigation, to about 20°.

If the distance between *Mars* and the Earth is not changing rapidly,[1] the water vapor and oxygen lines from *Mars* and the lines from the Earth will coincide. When this condition of coincidence exists, it is clearly a difficult problem to detect moderate quantities of water vapor and oxygen in the Martian atmosphere, for the evidence of Martian absorption will be overwhelmed by the absorption of the richly laden terrestrial atmosphere, especially if the observer be near sea-level. To hope for success, the observations should be made from a high-altitude station, at times when overlying air strata carry a minimum of water vapor, and when the planet is as near the zenith as practicable; observing the lunar spectrum, under identical conditions, for comparison.

Because of the faintness of the Martian and lunar spectra, it has been found that we are limited to low dispersion in visual observations, and that, when the distance between the two planets is constant or nearly so, low dispersion offers a more sensitive method than high dispersion, even when photography is employed.

Complying with the conditions in the two preceding paragraphs, the writers photographed the spectra of *Mars* and the Moon last September, from the summit of Mount Whitney. The conclusion drawn from that investigation was that the quantity of any water vapor then existing in the equatorial atmosphere of *Mars* was too small to be detected by the spectrographic methods available. This does not mean that the Martian atmosphere was carrying no water vapor, but only that the quantity must have been very small.

At times other than those when *Mars* is near opposition, the Earth and *Mars* are relatively approaching or receding from one another. Their relative velocity at quadrature may amount to 20^{km}, more or less, per second, depending upon the concurrence of favorable circumstances.

When Mr. CAMPBELL was photographing the spectrum of *Mars* in December, 1896, with a Rowland grating, fourth order,[2] 568 lines per millimeter (14,438 per inch), he realized that the Doppler-Fizeau principle offers great advantages, in theory at least, for solving the problem of the Martian atmosphere, for on photographs of the spectrum, made near quadrature, with sufficiently high dispersion, the Martian absorption lines and the terrestrial absorption lines should be separated. At that time (thirteen years ago) the method could not succeed, for all the prominent water vapor and oxygen lines are in the region on the red side of λ 5875, and the photographic dry plates then available were not sufficiently sensitive to record this region. Even in the fairly sensitive region λ 5700-λ 5800 the grating spectrograms of *Mars* were underexposed. The successes of recent years in sensitizing dry plates to yellow, orange, and red light have encouraged the present effort to apply the method.

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[1] More accurately, if the spectrographic velocity of *Mars* with reference to the Earth is constant or nearly so. This takes into account the relative velocity of *Mars* and the Sun.

[2] *Astrophysical Journal*, **5**, 236, 1897.

A spectrograph, designed by Mr. CAMPBELL to meet the requirements of the problem and used in connection with the 36-inch refractor, contains an excellent Michelson five-inch plane grating (15,000 lines per inch) which gives a brilliant spectrum in the second order on one side, and this was utilized. The wooden mounting of the spectrograph was designed at all points to resist differential flexure during the intervals of exposure to the planet and to the Moon. The instrument was adjusted, the observations were secured, and the measures and reductions of the spectrograms were all made by Mr. ALBRECHT.

It was planned to secure observations of *Mars* and the Moon on or near January 17, 1910, as the planet was in quadrature at that time. The spectrographic velocity of *Mars* with reference to the Earth was then 18.8^{km} per second, recession. Unfavorable weather delayed somewhat the carrying out of the program, but fortunately the velocity remained nearly constant for several weeks, until satisfactory observations were secured.

With the spectrograph adjusted for the orange region, which is rich in water-vapor absorption lines, spectrograms of *Mars* were secured on January 26th and 27th under poor atmospheric conditions, and on February 2d under excellent conditions, our atmosphere on that night being exceedingly dry. Measures of the available water-vapor lines on these spectrograms, eight to twenty-two in number, establish that they were displaced with reference to the lines of solar origin in the observed Martian spectrum by amounts on the three dates corresponding to velocities in the line of sight of 18.6, 19.1, and 17.8^{km} per second. The relative velocities of *Mars,* computed from our knowledge of the orbits of the Earth and *Mars,* amounted to 19.1^{km} per second. The discrepancy of 0.7^{km} per second is within the probable errors of the results yielded by the individual lines. The dispersion employed was such that the water-vapor lines originating in our atmosphere and any originating in *Mars's* atmosphere should have appeared side by side, though not clearly separated. If the absorptions by the two planets were equal, the two sets of lines of equal intensities should, in effect, have appeared as broad lines of double width, and the measured velocities should have been but half the computed velocities. The facts are that the terrestrial lines were not bordered nor increased in width by companion lines. When the micrometer wire was set successively in positions which Martian absorption lines would occupy, no traces of absorption were found in these positions. In effect, Martian absorption did not exist to such an extent as to be visible in the spectrum, or to influence the measurements referred to.

With the spectrograph adjusted to the so-called "alpha" region at λ 6280, which includes a large number of oxygen absorption lines, two spectrograms were obtained on February 3d. The observable oxygen lines, seven and six in number, were displaced with reference to the lines of solar origin by amounts corresponding to velocities in the line of sight of 18.8 and 17.4^{km} per second. The velocity computed from the elements of the orbits amounted to 19.1^{km}. The discrepancy of 1.0^{km} is likewise within the unavoidable error of measurement. Here again the terrestrial oxygen lines were not bordered nor doubled in with by Martian lines. When the micrometer was set in the positions for favorable Martian lines, no absorption was visible at these places.

The conclusions to be drawn from this investigation are: The quantity of any water vapor existing above unit area in the equatorial atmosphere of *Mars* was certainly less than one fifth that existing about Mount Hamilton under the excellent conditions prevailing on February 2d. The air temperature was 0° Centigrade, the relative humidity 33%, the absolute humidity 1.9 grams per cubic meter, and the zenith distance 55°. Likewise, the quantity of oxygen above unit area of *Mars* must be small in comparison with that in the Earth's atmosphere.